Evaluation of Recent Updates to the Spectroscopy of CO_2 and CH_4 in the Thermal Infrared Using Observations from TES and IASI

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1. Introduction

The accuracy of retrieved profiles of greenhouse gases such as CO_2 and CH_4 depends on the accuracy of the radiative transfer model used in the retrieval. Uncertainties in spectroscopic line parameters and continua are the primary limitations on the accuracy of molecular absorption in radiative transfer models, and so reducing these uncertainties is critical to ensuring future scientific progress. As part of our work with the TES instrument, AER regularly examines and validates potential spectroscopic improvements for inclusion in the forward model of the TES retrieval algorithm.

Here we present the results of several validation studies of recent updates to the spectroscopic parameters for CO_2 and CH_4 in AER's line-by-line radiative transfer model LBLRTM against measurements from the Tropospheric Emission Spectrometer (TES) made during the HIAPER Pole-to-Pole Observations (HIPPO) of Carbon Cycle and Greenhouse Gases Study and a global dataset of near-nadir measurements from the Infrared Atmospheric Sounding Instrument (IASI). We focus on the spectral residuals in the main thermal infrared bands of CH_4 and CO_2.

2. LBLRTM is an accurate and flexible radiative transfer model that is the basis of the forward model for a number of satellite programs, including TES and IASI.

LBLRTM v12.1 with AER v3.1 line parameters (released November 2011, rtweb.aer.com)

Spectroscopy based on **HITRAN 2008** (Rothman *et al.*, 2009) along with:

- H_2O
  - Line positions and intensities (10-2500 cm^{-1}): Coudert *et al.* (2008).
  - Air-broadened half-widths, temp. dep. and pressure shifts (350-667 cm^{-1}): Delamere *et al.* (2010).
- CO_2
  - Lamouroux *et al.* (2010) first order line coupling parameters (P-,Q-, and R-branches).
  - Line intensities and positions (597-2500 cm^{-1}) from the Carbon Dioxide Spectral Database (CDSD) (Tashkun *et al.*, 2003; Flaud *et al.*, 2003).
- CH_4
  - HITRAN 2008 with first-order line coupling for ν_4 and ν_3 bands (Tran *et al.*, 2006).
- **MT_CKD v2.5.2 Continuum**
  - Updates to CO_2 and self-broadened H_2O in the 2400 cm^{-1} region (Mlawer *et al.*, 2012).

LBLRTM v11.3 with TES v1.4 line parameters (released November 2007)

Spectroscopy based on **HITRAN 2000** (Rothman *et al.*, 2003) along with:

- H_2O from HITRAN 2006 updates.
- CO_2 P-, Q-, and R-branch line coupling based on Niro *et al.* (2005).
- CH_4 (922.65-1678.33 cm^{-1}) and CO supplied by Linda Brown of JPL.
- O_3 from Wagner *et al.*, 2002.
- **MT_CKD v2.0 Continuum**

LBLRTM v9.4+ with AER v1.0 line parameters (released January 2005)

As in LBLRTM v11.3 with TES v1.4 except CO_2 Q-branch line coupling only and MT_CKD v1.2 Continuum.

3. Methods

TES is a Fourier Transform Spectrometer (FTS) aboard the NASA Aura polar orbiting satellite. Spectral range 650–1325 cm^{-1} and 1900-2250 cm^{-1}, 0.06 cm^{-1} resolution, footprint of 5.3×8.3 km.

IASI is a FTS aboard the MetOp-A polar orbiting satellite. Spectral range 645–2760 cm^{-1}, 0.5 cm^{-1} resolution, footprint of ~18 km, swath of ~2400 km.

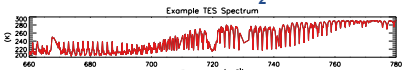
a) TES-HIPPO forward model (FM) study
We use TES spectra measured during the HIPPO I campaign (Jan. 2009) that are nearly coincident with the aircraft. We use the observed aircraft profiles of CO_2 and CH_4 (supplied by the HIPPO science team, S. Wofsy, lead PI) and examine the forward model residuals using different line parameters.

b) TES-HIPPO retrieval study
We use spectra measured by TES during the HIPPO I and II campaigns. We performed retrievals of temperature, H_2O, CO_2, HDO, N_2O, CH_4, cloud OD, and surface emissivity using different line parameters.

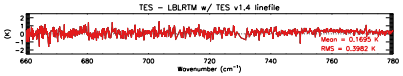
c) IASI retrieval study
We use a subset of the spectra from Matricardi, 2009. These are clear-sky, nighttime, ocean profiles. We performed retrievals of temperature, H_2O, O_3, CO, and CH_4. A priori profiles are from ECMWF model or TES climatology

4. Preliminary TES-HIPPO FM Results: CO_2

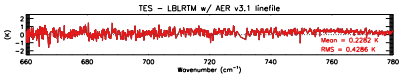
Example TES Spectrum



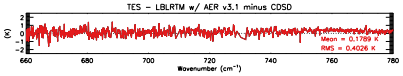
Mean Residuals LBLv11.3 w/TES v1.4



Mean Residuals LBL v12.1 w/AER v3.1

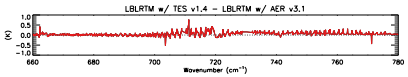


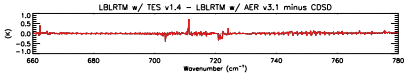
Mean Residuals LBLv12.1 w/AER v3.1 Minus CDSD



Using the CDSD positions and strengths included in LBLRTM v12.1 (and AER v3.1) increases the RMS of the mean forward model residuals in the CO_2 ν_2 band.

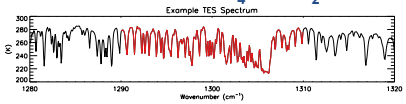
Left: Mean residuals for 6 scans over ocean with cloud OD < 0.1. Below: Mean differences between LBL runs using the TES v1.4, AER v3.1, and AER v3.1 minus CDSD line parameters.



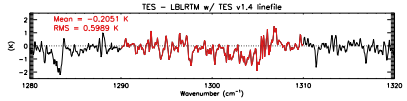


5. Preliminary TES-HIPPO FM Results: CH_4 and N_2O

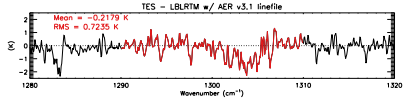
Example TES Spectrum



Mean Residuals LBL v11.3 w/ TES v1.4



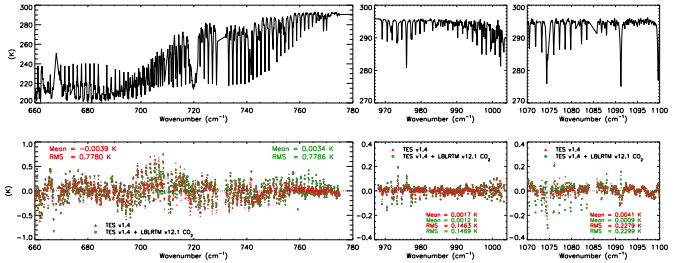
Mean Residuals LBL v12.1 w/ AER v3.1



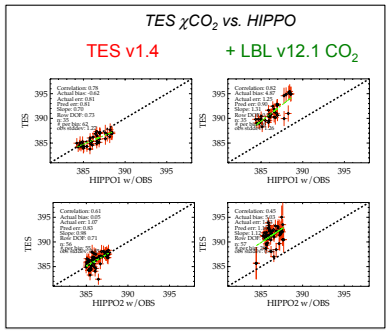
The updated CH_4 and N_2O spectroscopic parameters included in LBLRTM v12.1 don't appear to improve the forward model residuals in this spectral range.

6. TES CO_2 Retrievals

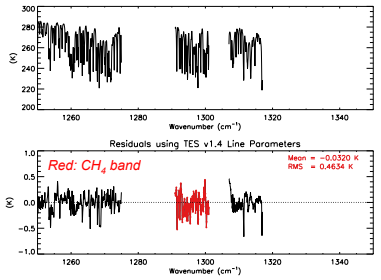
Red: TES v1.4 line parameters
Green: TES v1.4 plus CO_2 from LBLRTM v12.1 (i.e., AER v3.1 line file)



While adding the CDSD positions and strengths from LBLRTM v12.1 to TES v1.4 has a negligible impact on the mean and RMS of the residuals after the CO_2 retrieval, the correlation between the TES retrieved χCO_2 and the HIPPO profiles is degraded (see box at right).



7. TES CH_4 Retrievals

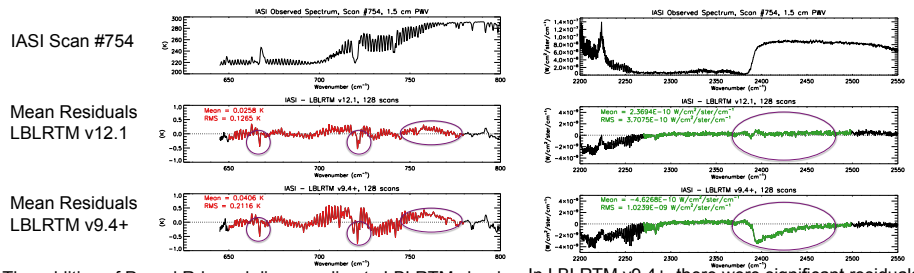


The TES residuals show a slight negative mean between 1290−1301 cm^{-1}, agreeing with the IASI results (see below)

However, the TES CH_4 retrieval approach, with its simultaneous retrieval of N_2O, better minimizes the residuals between 1260−1275 cm^{-1}.

8. IASI CO_2 bands after T_{atm} Retrieval

Red: ν_2 retrieval microwindow.
Green: Not included in ν_2 retrieval.

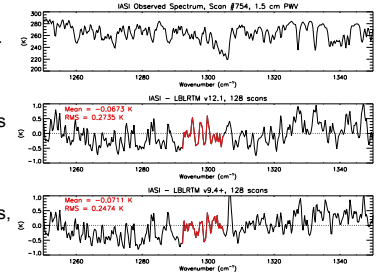


The addition of P- and R-branch line coupling to LBLRTM clearly improved the spectroscopy on either side of the CO_2 Q-branch at 720 cm^{-1}. The major remaining residual features in LBLRTM v12.1 are negative residuals in the 667 and 720 cm^{-1} Q-branches and positive residuals between 750−770 cm^{-1}.

In LBLRTM v9.4+, there were significant residuals near the ν_3 bandhead after the ν_2 band temperature retrieval. Recent updates to the MT_CKD continuum included in LBLRTM v12.1 have dramatically improved the model performance in this region.

9. IASI CH_4 band

Red: Retrieval microwindows.



It is not clear if the CH_4 spectroscopic updates have improved the residuals. While the mean residual is now closer to 0, the RMS is larger.

The retrieved CH_4 profiles (not shown) have a clear high bias, suggesting that spectroscopic errors remain in this region.

10. Conclusions

The LBLRTM v12.1 CO_2 spectroscopy is remarkably consistent between the CO_2 ν_2 and ν_3 bands. However, the performance of the TES CO_2 retrieval, which does not use the CO_2 ν_3 band, is degraded by adding the CDSD positions and strengths in LBLRTM v12.1 to the TES line parameters.

The LBLRTM v12.1 CH_4 spectroscopy is not a clear improvement over that in the TES v1.4 line parameters or LBLRTM v9.4+. Strong residual features remain between 1295−1301 cm^{-1}, suggesting further spectroscopic work is needed.

References

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